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This report describes the progress made during the second and final year of an equipment grant which has provided a common computing environment for four laboratories conducting basic research in perception and cognition at the University of Minnesota. Research in the Cognitive Psychology Laboratory has focused on developing a computer model of the interaction of declarative and procedural knowledge in skill acquisition. In the Visual Psychophysics Laboratory several emage-enhancement algorithms have been developed as well as psychophysical procedures for evaluating those algorithms. Research in the Auditory Psychophysics Laboratory has concentrated on developing a model of the detection and recognition of complex auditory signals. In the Psycholinguistics Laboratory a computer model of text comprehension and recall has been constructed and several experiments have been completed that verify basic assumptions of the model and show a good correspondence between its performance and that of college student subjects.

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COMPUTING SUPPORT FOR BASIC RESEARCH IN PERCEPTION AND COGNITION

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Abstract

This report describes progress made during the second and final year of an equipment grant which has provided support for a common computing environment for four laboratories conducting basic research in perception and cognition at the University of Minnesota. Research in the Cognitive Psychology Laboratory has focused on developing a computer model of the interaction of declarative and procedural knowledge in skill acquisition. In the Visual Psychophysics Laboratory several image-enhancement algorithms have been developed as well as psychophysical procedures for evaluating those algorithms. Research in the Auditory Psychophysics Laboratory has concentrated on developing a model of the detection and recognition of complex auditory signals. In the Psycholinguistics Laboratory a computer model of text comprehension and recall has been constructed and several experiments have been completed that verify basic assumptions of the model and show a good correspondence between its performance and that of college student subjects.

This report describes the progress made during the second and final year of AFOSR-86-0280, "Computing Support for Basic Research in Perception and Cognition". This equipment grant has provided a common computing environment (a network of Sun workstations and IBM micro-computers) for four laboratories within the Psychology Department at the University of Minnesota. These laboratories include the Visual Psychophysics Laboratory headed by Gordon E. Legge, the Auditory Psychophysics Laboratory directed by Neal F. Viemeister, Mary Jo Nissen's Cognitive Psychology Laboratory, and the Psycholinguistics Laboratory directed by Charles R. Fletcher. In the last year we have completed the acquisition and installation of the equipment requested in our original proposal. We have also made substantial scientific progress. The following sections of this report outline the research goals of each laboratory and describe the progress that as been made toward achieving those goals.

Acquisition of Skilled Performance

Much of the work in the Cognitive Psychology Laboratory involves the investigation of distinctions between procedural and declarative memory systems and their interaction in the acquisition and expression of skills. Progress has been made during the last year on experiments using both normal and amnesic individuals as subjects. Some of this work has culminated in the completion of a doctoral dissertation by Peter Bullemer and the submission of two articles for publication in the Journal of Experimental Psychology.

Progress has also been made toward the goal of developing a computer simulation of our experimental findings. Because it is this work in particular that was facilitated by the AFOSR grant, its current status will be summarized.

The intent of the simulation is to find a neurally plausible account of the memory characteristics revealed by the serial reaction time (SRT) paradigm, which is used in most of our experimental work. This task requires subjects to make a speeded response on each trial to a light appearing in one of four locations on a video monitor. A ten-trial sequence of light positions is repeated throughout a block of 100 trials.

Learning of the sequence is evaluated implicitly by measuring facilitation of performance - i.e., by determining whether reaction time (RT) increases when subjects are transferred to a random sequence following training on this repeated sequence.

Various neural net approaches have been developed by Charles Sheaffer working in the Cognitive Psychology laboratory. These have been implemented in Lucid Common LISP on a Sun 3/160 workstation. The first simulation was an implementation of the back-propagation technique (Rumelhart & McClelland, 1986). The network was composed of three layers: an input layer, an output layer, and a hidden layer. These were connected in a feed-forward manner, each layer being fully interconnected to the succeeding layer. Each output node was connected to a single input node, each connection being of a fixed weight. In addition, each input node had a recurrent connection to itself with a fixed weight. The purpose of the recurrent connections was to allow the network to save previous states, thus enabling it to learn sequences of inputs (Jordan, 1986). The representation was local; each input node corresponded to one stimulus, each output node to one response. The network was able to reproduce the ten-item sequence in the absence of external inputs after some 1500 learning trials, thus verifying the feasibility of the method.

The major adaptation made to simulate the SRT task itself was to leave a particular input on until the associated output reaches criterion, adjusting weights after each cycle. The number of cycles required to activate an output unit was considered to correspond to the RT to the given input. The hypothesis was that the number of cycles required to activate an output unit would decrease with each trial. This was, in fact, the case; thus, the network succeeded in establishing a learning curve over four blocks of trials.

It turned out, however, that four blocks was not nearly enough to establish stable learning of the sequence. When the network was allowed to run for thousands of trials in an attempt to converge on stable learning, it reached a floor of response times on the order of eight to ten cycles. This was due to the fact that several cycles were required to drive an activated output back to zero after the associated input was turned off. In Jordan's terms, what was actually being learned was a sequence of roughly 90 items -- i.e., ten items with nine cycles per item. This exceeds the network's capacity to save states via its recurrent connections. When run with no input, the network initially reproduced the sequence, but accuracy gradually degraded as it continued to run.

In an effort to improve the level of learning, a change was made in which, after an output node had been activated to criterion, its activation was held at zero for eight cycles. This prevented the changing of any weights that would drive the output back to zero. Response times improved, reaching an asymptote of two or three cycles. Additionally, when presented with a random sequence following training on the repeating sequence, the network slowed in its responses by about the same amount as amnesic Korsakoff patients.

When the SRT task was simulated with this same eight-cycle repression of activation for recently activated nodes, the network also yielded a qualitative match of human subjects' serial position curves on this task -- i.e., the tendency for some items in the sequence to be responded to faster than others. The fact that the eight-cycle repression kept nodes from being activated when their input might otherwise have forced them to do so led to a prediction that some sequences might be more difficult (i.e., be associated with slower responses) than others. The simulation was used to choose a particularly difficult sequence for testing on human subjects. Human performance was degraded as expected, and the serial position curve qualitatively matched the prediction.

Several problems are posed by the back-propagation model. First, it provides only qualitative matches to human subjects' learning curves and serial position curves. While patterns of change in the curves were similar, slopes at particular points were not simulated well. Second, the back-propagation technique suffers from the weakness of not being neurologically plausible after all (Grossberg, 1987). Finally, the eight-cycle repression process is without principled justification.

To address these concerns, a second simulation is being developed. This simulation exploits a variant of the competitive learning technique (Rumelhart & McClelland, 1986; Grossberg, 1987). The new network is composed of 16 nodes. Again, the nodes are arranged in three feed-forward layers, with four input and four output nodes. However, the hidden layer now has eight nodes, and the interconnection scheme has changed. The four input nodes are each connected to two of the hidden nodes. In each of the hidden node pairs, one transmits activation directly to the output node corresponding to its input node; the other is fully interconnected with the set of four output nodes. There are no recurrent connections.

The hidden node that directly connects an input node to the corresponding output node amounts to a bias to respond, for example, without output #4 when input #4 occurs. This bias corresponds to the ease with which humans make spatially compatible responses, and with the fact that subjects in the SRT task quickly learn to respond correctly on each trial. The result of this direct connection should be that the learning curve will not be dominated by the learning of this connection, as it was in the initial simulation. Thus, there should be a closer match between the learning curves of the simulation and the human subjects.

All connection weights between the input and hidden layers are fixed. The hidden layer exists solely to allow the introduction of the biasing nodes. Sequence learning takes place on all connections from the hidden layer to the output layer. Preliminary simulations with handcrafted weights on the upper set of connections reveal serial position curves that more closely correspond to the human data. This improvement is accomplished by allowing hidden nodes to retain activation subject to a decay factor.

Work is continuing on the implementation of the learning algorithm. In addition, an attentional mechanism that allows encoding of vertical associations, or chunks (Wickelgren, 1979), is being developed. Parameters affecting this mechanism should allow us to simulate dual-task conditions as well as the role of explicit knowledge (awareness of) the sequence.

Image Enhancement in Human Vision

In the Visual Psychophysics Laboratory AFOSR funding has permitted us to develop the following hardware configuration: A Conrac 7241 high-performance RGB color monitor displays true-color images from three Imaging Technology FG-512/AT video frame buffers controlled by an IBM AT. The AT is linked into our Sun network, along with two Sun workstations in our lab. The Sun network is used for image storage and computationally intensive image processing, with the IBM AT used for real-time control in experiments. In addition we now have an RGB video color camera for image capture.

We have developed color-calibration software for measurements of equiluminance via heterochromatic flicker and minimally-distinct border methods. We have developed software that loads look-up tables to present colors of specified luminance and CIE chromaticity coordinates (within the Conrac's gamut of colors). In addition, we use the HIPS image-processing software for handling and processing images.

<u>Color Contrast and Reading</u>. As an experiment to launch our work on color and pattern (and one related to our work on the psychophysics of reading), we are examining how color contrast compares with luminance contrast in their effects on reading speed. Imagine reading text composed of red letters on an equiluminant green background. Since reading is a dynamic visual process, the recent proposal that motion and other high-speed visual processes are mediated by a "color blind" pathway predicts that reading should be severely impaired by equiluminant conditions. Our early results indicate that this is not at all so. Equiluminant text having sufficiently different chromaticity coordinates for the letters and background can support reading rates as high as those for text of high luminance contrast.

Contrast Coding: Feature Detectors or Channels It is generally agreed that there exists an early sensory representation based on spatial frequency and orientation, the channel model. There remains, however, an important gap in our knowledge. The channel model is based primarily on contrast-detection data. The relevance of the channel model to suprathreshold pattern processing has been challenged. The challenge hinges on evidence for spatially local "feature detectors" as alternatives to channels. Proposals for the types of local features include luminance gradients and local contrast (i.e. differences between adjacent luminance peaks and valleys in a stimulus).

We have developed a contrast-discrimination paradigm in which the predictions of channel and "local-feature" models are pitted against one another in the context of suprathreshold pattern discrimination. In our yoked-contrast procedure, the subject distinguishes between pairs of compound sine-wave gratings. In the discrimination task, the contrasts of the two grating components are varied in equal and opposite directions, keeping the overall contrast fixed. Predictions of the channel model are based on the responses of the channels tuned to the separate components. Predictions of the feature models are derived from spatial characteristics of the waveforms.

We have collected a substantial amount of data from several subjects at different contrast ranges and frequency ratios. Preliminary analysis indicates rather equivocal support for the channel model. Viewed from a different perspective, a hybrid model may afford the best account of the data. We are planning to implement A.B. Watson's model on our computer and compare its predictions with our results.

We have been examining the feature vs. channel debate in a second context: stereopsis. In a past study, we made extensive measurements of the effects of contrast and spatial frequency on stereopsis. We have used these data to test proposals for the nature of the "matching primitives" in stereopsis. For example, we have extended the Marr & Poggio (1979) model so as to examine its predictions for disparity detection. Despite our early optimism that it would work well, mathematical analysis and computer simulation are leading us to the conclusion that this model cannot account for our contrast data. There may also be difficulties in applying the "centroid" model of spatial localization proposed by Watt and Morgan.

Psychophysical Evaluation of Image Enhancement. We have developed a psychophysical method for evaluating the enhanced visibility of processed images. Since our lab has an historic interest in models of contrast coding, we are most interested in algorithms that modify images by "enhancing contrast." Our procedure involves measuring contrast thresholds for recognizing targets in enhanced and original images. If an image has been enhanced effectively, it should be recognizable with greater contrast attenuation.

We have been looking in detail at gray-level histogram equalization. Following the medical-imaging work of S. Pizer, we have implemented a form of local histogram equalization with interpolation. We have taken face recognition as our task: same vs. different face, smiling vs. not smiling, front vs. profile view. Our procedure has revealed a small but reliable enhancement due to histogram equalization. The enhancement is greatest when the image is broken into 2 X 2 or 4 X 4 local patches prior to histogram localization. We are evaluating the possibility that the enhancement can be accounted for entirely by changes in RMS image contrast associated with the enhancement algorithm.

Graphical Perception. Graphical perception refers to the part played by visual perception in analyzing graphs. Computer graphics has stimulated interest in the perceptual pros and cons of different formats for displaying data. One way of evaluating the effectiveness of a display is to measure the efficiency (as defined by signal-detection theory) with which an observer extracts information from the graph. We measured observers' efficiencies for detecting differences in the means or variances of pairs of data sets sampled from Gaussian distributions. Sample size ranged from 1 to 20 for viewing times of 0.3 or 1 second. The samples were displayed in three formats:

as numerical tables, as scatterplots and as luminance-coded displays. Efficiency was highest for the scatterplots (approximately 60% for both means and variances) and was only weakly dependent on sample size and exposure time. The pattern of results suggests parallel perceptual computation in which a constant proportion of the available information is used. Efficiency was lowest for the numerical tables and depended more strongly on sample size and viewing time. The results suggest serial processing in which a fixed amount of the available information is processed in a given time.

Detection and Recognition of Complex Auditory Signals by Human Observers

The research proposed for the Auditory Psychophysics Laboratory consisted of experimental and theoretical work aimed at developing a descriptive model which can account for the detection and recognition of spectrally complex auditory signals. Since initiation of this project, two major experimental studies have been completed and two are in progress. One of the completed studies examines the ability to extract information about temporal relationships between stimulation in different frequency-selective auditory "channels". More specifically, we have shown that relatively small phase differences between the envelopes of sinusoidally amplitude-modulated tones can be detected over a wide range of modulation frequencies and over a wide range of relative carrier frequencies. The major conclusion of this research is that the auditory system can perform a true "cross-channel" comparison and that the "within-channel" interactions which are present in most complex signals can not explain certain types of complex perceptions. The implication is that this higher order ability must be considered to understand perception of complex auditory signals. This research was presented at the November, 1987 meeting of the Acoustical Society of America and a paper is in preparation.

A research project which is a "spin-off" from that described above is examining adaptation to AM waveforms. It has been known that thresholds for detecting AM can be elevated by previous exposure to AM tones but the literature is very incomplete on potentially important parametric effects. We are in the initial stages of examining such effects and are concentrating on adaptation "tuning" and on possible adaptation across carrier frequencies. A primary concern is that adaptation to AM may be involved in the many recent studies, including our own, that employ AM waveforms with large modulation depths.

The second completed project pursued a phenomenon which questions our understanding of basic auditory processing. Specifically, we have shown that sweep-frequency maskers can produce substantially more masking of a brief tonal probe than does an "unswept" masker at the probe frequency. The swept masker has far less energy in the "critical band" centered at the probe frequency and therefore should produce less masking. Our research has ruled out several possible explanations for this phenomenon and has indicated very peculiar masker-level dependencies. These dependencies suggest that something other than traditional "energetic" masking is occurring and, possibly, that the phenomenon reflects a complex process of envelope waveshape discrimination. The research was presented at the November, 1987 meeting of the Acoustical Society of America and a paper is in preparation.

A project currently in progress is examining the general question of how well a given envelope periodicity can be detected in the presence of other periodicities. The "modulation masking" data we have collected so far indicate that if there is tuning for periodicity, it is very broad. In addition to certain practical implications for hearing aids and cochlear implants, this suggests that certain types of proposed coding schemes, specifically those employing periodicity tuning in the CNS, are probably incorrect.

The theoretical work supported by this grant has been preparatory and has primarily involved implementing the Sun/UNIX system acquired through the support of this grant. Two major accomplishments have been achieved. We have implemented a signal processing package, ISPUD, on the Sun. This is a powerful, LISP-like environment developed at MIT and run under their VAX/VMS system. Extensive modifications were necessary to run this package under UNIX. We have begun using ISPUD/UNIX for simulations of simple auditory phenomenon and for generation of complex waveforms to be used in our psychophysical research. We have also incorporated Patterson's "gammatone" filter bank and Meddis' transducer model into ISPUD. This provides a fairly realistic representation of the response across an array of auditory nerve fibers to arbitrary stimuli.

The second project involved implementing a realistic cochlear model (Allen, 1985) on the Sun. This provides part of the front end for a more detailed model and is fundamental to the theoretical work proposed under this project. The model is at the stage where it has helped us to understand the possible basis for the sweep-frequency masking paradox described above.

A Process Model for the Comprehension and Recall of Texts

The research conducted in the Psycholinguistics Laboratory has been directed toward developing and testing a computer model of text comprehension and recall. Substantial progress has been made toward achieving this goal and a manuscript describing the model (as well as its ability to predict how a text will be recalled) is now in preparation. The model is implemented in Sun Common LISP and runs on a Sun 3/160 workstation. It includes a comprehension component and a free recall component. The comprehension component of the model takes as input a list of semantic propositions representing the meaning of a text, and a list of causal relationships among those propositions. It adds propositions to a limited-capacity short-term memory one at a time, just as human readers do. As each propositions is added to short-term memory a link is created between it and any other propositions in short-term memory. A strength is assigned to each link, depending on the nature of the semantic relationship between the linked propositions. Causally related propositions are assigned a stronger link than referentially related propositions, which are assigned a stronger link than propositions with no semantic relationship. Each time a sentence boundary is encountered, short-term memory is purged of all but a few propositions in order to make room for the next sentence. Only propositions with causal antecedents but no consequences in the preceding text are retained in short-term memory. This assumes that readers engage in a simple form of causal reasoning during comprehension, always focusing their attention on the end of the causal chain that can be traced backward to the opening of the text. After short-term memory has been purged, the strength of association between all propositions not deleted is incremented. This process results in a representation in long-term memory that consists of a connected network of propositions with strengths assigned to each link. The strength of association between any two propositions is determined by the nature of the semantic relationship between them and the amount of time they spend together in short-term memory.

The free recall component of the model takes as input the propositional network produced by the comprehension component. It's output is a list of "recalled" propositions. This part of the model includes a strategic process that selects retrieval cues and a stochastic retrieval process that uses those cues to probe long-term memory and return a recalled proposition. The strategic process always selects as cues propositions whose antecedents, but not consequences, have been recalled. This amounts to assuming that recalling a text also involves causal reasoning, that a subject trying to recall a text will attempt to find a sequence of propositions that form a causal chain linking the opening of the text to its final outcome. The retrieval process used by the model is based on Gillund and Shiffrin (1984, Psychological Review), a model that has been well tested in the list-learning domain.

As an overall test of the model it was run 100 times each on four simple narrative texts (each ten sentences long). The resulting free recall probabilities for each proposition were compared to those observed in human subjects. The correlations between the predicted and observed recall probabilities for the four texts ranged from a low of .51 to a high of .72. This indicates substantial similarity between the performance of the model and human readers. This success can be attributed to three key elements of the model: (1) The process that determines the contents of short-term memory during comprehension. (2) The assumption that the strength of association between two propositions is determined by the by the nature of the semantic relationship between them. (3) The process that selects retrieval cues during recall. When any of these elements is removed from the model, a significant decrement in its performance is observed.

Our model has several psychologically meaningful assumptions built into it. First is the assumption that subjects always retain in short-term memory the last proposition (or group of propositions) with antecedents but no consequences in the preceding text. A number of experiments have been completed to verify this assumption. In one study, the length of time that a proposition remains in short-term memory and the number of other propositions it becomes connected to as a result was predicted by the model for each proposition in eight simple narrative texts. These two variables were found to account for more than 30% of the variance in the free recall performance of a group of college student subjects. Several competing models of short-term memory allocation during comprehension were examined, but none performed as well. This research is described in a paper just published in the Journal of Memory and Language. In a second experiment, reading time (per clause) was found to vary as a function of the causal structure of a text. Specifically, each causal connection a clause has to other clauses increases its reading time--but only if the propositions from those other clause remain in short-term memory (according to the model). Moreover, when no causal connections are found between a new sentence and the contents of short-term memory (again as predicted by the model) reading time increases, reflecting the time needed to retrieve the new sentence's causal antecedents from long-term memory. A manuscript describing this research (by Bloom, Fletcher, van den Broek, Reitz, & Shapiro) has been submitted for publication. In three additional experiments, a variety of procedures (e.g., probe recognition and reading time) were used to demonstrate that when a sentence is followed by a causal antecedent it remains more available than when it is followed by a causal consequence. A manuscript describing this research (by Fletcher, Hummel, & Marsolek) is now under review for publication. Taken together, these experiments provide strong support for the model's assumptions about the allocation of short-term memory during comprehension.

Our assumption that the strength of association between two propositions from a text depends on the on the nature of the semantic relationship between them has also been tested experimentally. In a series of cued-recall experiments we have been able to show that causally related propositions are more strongly associated in long-term memory than referentially related propositions, which (in turn) are more strongly associated than propositions that co-occur in short-term memory but have no semantic relationship to one another. This confirms a second basic assumption of our model and a manuscript describing this research is now in preparation. A third assumption that needs to be verified, but has not yet been examined, is that causal reasoning determines the selection of retrieval cues during the recall of a text. We are now planning a series of experiments that will test this assumption.

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<u>In Preparation/Submitted</u>:

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Legge, G.E., & Gu, Y. Stereopsis and contrast. Submitted for publication.

Legge, G.E., Gu, Y., & Luebker, A. Efficiency of graphical perception. Submitted for publication.

Nissen, M.J., Willingham, D.B., & Bullemer, P. On the nature and specificity of procedural learning. Submitted for publication.

Hartman, M., Knopman, D.S., & Nissen, M.J. Implicit learning of new verbal associations. Submitted for publication.

Viemeister, N.F. Evidence for cross-channel processing in detection of envelope phase disparity. In preparation.

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Peter Bullemer (Graduate Student - Defended Ph.D. Dissertation in June, 1988. Dissertation Title: "On the relationship between attentional processes and memory systems in the expression of skill: A combined cost-benefit and dual-task approach".)

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Conference and Colloquium Presentations

<u>Presented in 1987</u>:

Bloom, C.P., Fletcher, C.R., Reitz, L., & Shapiro, B. An online assessment of causal reasoning in the comprehension of narrative texts. Paper presented at the annual meeting of the Psychonomic Society. Seattle, WA, November, 1987.

Fletcher, C.R. A model of causal reasoning in comprehension: Implications for education. Paper presented at the annual meeting of the National Reading Conference. St. Petersburg, FL, December, 1987.

Fletcher, C.R., & Bloom, C.P. Causal Reasoning in the construction of a propositional textbase. Paper presented at the annual meeting of the Cognitive Science Society. Seattle, WA, August, 1988.

Gu, Y., Legge, G.E., & Luebker, A. Efficiency of graphical perception. Invited paper, Spatial Displays and Spatial Instruments: A Symposium and Workshop. Sponsored by NASA and University of California, Berkeley, Asilomar, September, 1987.

Nissen, M.J., Willingham, D.B., & Bullemer, P. On the nature and specificity of procedural learning. Paper presented at the annual meeting of the Psychonomic Society, Seattle, WA, November, 1987.

Viemeister, N.F. Evidence for cross-channel processing in detection of envelope phase disparity. Paper presented at the annual meeting of the Acoustical Society of America, Miami, FL, November, 1987.

Viemeister, N.F. Masking of short tone bursts by frequency sweeps. Paper presented at the annual meeting of the Acoustical Society of America, Miami, FL, November, 1987.

Presented in 1988:

Bloom, C.P., Fletcher, C.R., Reitz, L., & Shapiro, B.P. Causal reasoning in the comprehension of narrative texts. Paper presented at the XXIV International Congress of Psychology. Sydney, Australia, August, 1988.

van den Broek, P., Fletcher, C.R., & Marsolek, C.J. Cognitive processes in composition: The role of causal reasoning. Paper presented at the annual conference of the American Educational Research Association. San Francisco, CA, March, 1988.

Fletcher, C.R., Chrysler, S.T., & Bloom, C.P. Causal coherence and the representation of sentences in memory. Poster presented at the annual meeting of the Psychonomic Society. Chicago, IL, November, 1988.

Legge, G.E., & Gu, Y.. Stereo acuity and the localization of zero crossings. Paper presented at the annual meeting of the Association for Research in Vision and Ophthalmology, Sarasota, FL, May, 1988.

Nissen, M.J. Explicit and implicit knowledge in memory and amnesia. Colloquium presentation to the Department of Psychology, University of North Carolina, February, 1988.

Nissen, M.J. Memory and awareness in a case of multiple personality disorder. Contribution to symposium on Memory in Multiple Personality Disorder, held at the annual meeting of the Rocky Mountain Psychological Association, Snowbird, Utah, April, 1988.

Nissen, M.J. Understanding memory by studying amnesia. Invited presentation at the annual meeting of the Minnesota Psychological Association, Minneapolis, MN, May, 1988.

Nissen, M.J. Disorders of memory and cognition in Alzheimer's disease. Invited presentation at the James S. McDonnell Foundation Summer Institute in Cognitive Neuroscience, Harvard University, June, 1988.

Viemeister, N.F. Psychophysics of envelope perception. Paper presented at the University of California, San Francisco, CA, May, 1988.

Viemeister, N.F. Dynamic Aspects of hearing. Paper presented at the Institute for Sensory Research, Syracuse, NY, September, 1988.